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Sustainable systems for management of the weaner pig through nutrition (NUTWEAN)

by

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This is a Defra-sponsored Sustainable Arable Link Project (LK0652) that ran for four years from September 2003. The project was sponsored by Defra (£644,088), HGCA (£142,500, Project No. 2688) and MLC (£319,200), with industrial support from ABNA Ltd (£50,000), Provimi Ltd (£60,000), Primary Diets Ltd (£50,000), Frank Wright Ltd (£25,000) making a total of £1,290,788.

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Abstract

NUTWEAN aimed to develop sustainable management systems for weaner pigs without antimicrobial growth promoters (AGP) whilst maximising use of home-grown cereals and oilseeds. Pre- and post-weaning nutrition was modified to exploit the potential of dietary components to enhance gut health and food intake.

- Sodium butyrate, but not inulin, improved gut development and feed conversion ratio pre-weaning, but without post weaning benefits.
- *In vitro* rheological characterisation may predict *in vivo* starch digestibility from cereals. Soft wheat is associated with improved nutritional value in terms of gut environment and nitrogen digestibility.
- Micronisation or extrusion increases wheat's nutritional value. Extrusion may overcome penalties of its endogenous α-amylase on performance.
- Soluble non-starch, "non-viscous" polysaccharides (e.g. inulin) could minimise post weaning diarrhoea whilst maximising performance, especially at high protein levels and increased disease risk.
- Using low protein diets in the immediate post weaning period maintains gut health and decreases risk of post weaning diarrhoea, especially in younger pigs and under disease challenge. The associated small penalty on growth does not seem to affect long term performance.
- Inclusion of formic acid or phytase did not affect performance or gut health, but phytase may be an alternative to inorganic phosphorus.
- Micronised whole rapeseed didn't adversely affect feed conversion ratio or feed cost/kg gain at dietary levels greater than previously accepted.
- Outdoor rearing results in better performance around weaning, and improved gut development, but pre-weaning mortality rate may be elevated. Delayed weaning to 6 weeks of age reduced performance of indoor but not of outdoor reared piglets. Rearing environment did not interact with the positive responses observed to use of AGP.
- Under commercial conditions, pigs offered high quality diets (cooked cereals, animal protein sources, extruded wheat), had improved health and performance in the immediate post weaning period only, with no added benefits in the longer term (e.g. until slaughter).

NUTWEAN's expected benefits include:

- decreased post-weaning diarrhoea, leading to improved health and welfare
- increased profits from improved post weaning performance
- improved feed efficiency resulting in a decrease in nitrogen output and reduced environmental impact
- potential for increased market for UK cereals and oilseeds
- reduced environmental burden of minerals and chemical residues
- reduced dependency on antimicrobial agents.

NUTWEAN's results have been widely communicated through over 20 refereed and review papers, 25 conference papers, numerous articles in technical magazines, and presentations at industry meetings. Further KT activities are planned, whilst commercial partners have taken up outcomes in their research and diet formulation portfolios. The project demonstrated nutritional and health benefits of cereals and oilseeds in weaner diets. This information will enable the arable and pig sectors to work together to ensure arable farmers supply e.g. wheat of optimum quality for inclusion in pig feeds.

SUMMARY

Introduction

The period of growth in the first few weeks after weaning has a profound influence on lifetime performance as more rapid growth and better feed utilisation will reduce the time it takes for pigs to reach slaughter weights, and reduce environmental loading of nutrients (especially N and P). Such improved feed efficiency and fewer days to slaughter significantly reduces waste output. For example, improving feed efficiency by 12% (1.6 *vs* 1.4) reduces N excretion and P excretion by 4 kg/sow/year and 0.6 kg/sow/year, respectively. Model calculations (Dr P Gill, *personal communication*) estimate a reduction in N secretion of 0.5 kg/pig as lifetime growth improves from 500 to 590 g/day [days to slaughter reduced from 180 (current industry average) to 155 days (BPEX 4 year target)]. For a 2,000 sow unit, this is equivalent to a reduction of 22 tonnes of N year, along with significant reduction in odour emissions to the surrounding countryside.

The routine inclusion of in-feed antimicrobials and pharmacological levels of minerals, such as ZnO and $CuSO_4$, have long been used to improve performance and as means of increasing production efficiency and protection against enteric disorders in newly weaned pigs. However, due to increasing public and scientific concerns about the possible association between in-feed antimicrobials and antibiotic resistance to bacterial infections in humans, the use of in-feed antimicrobial growth promoters (AGPs) were banned within the EU from 1st January 2006 EU (Regulation (EC) No. 1831/2003). Furthermore, the EU Scientific Committee on Animal Nutrition is investigating Maximum Permitted Levels for Zn and Cu in diets to reduce the potentially devastating effects of these heavy minerals in the environment.

These restrictions place the weaner pig at greater risk to post-weaning enteric disorders leading to a demise in welfare, compromised food safety, and increased resource use (physical and financial) as growth rates and feed efficiency deteriorate. Consequently, to remain competitive in the global market and comply with both corporate and government policy that promotes sustainable pig farming through environmental harm minimisation, enhanced welfare and safe food, the British pig Industry must seek sustainable solutions for weaner pig management without dietary antimicrobial agents.

Objective

The aim was to develop sustainable systems for the management of the weaner pig through nutrition, in the absence of any input from antimicrobial or growth promoting agents. This aim was achieved by imposing nutritional manipulations on the pig pre- and post-weaning, in different lactation environments and different weaning ages, which exploited the potential of dietary components to enhance the gut development, improve food intake post-weaning, affect resident microbial populations and thus enhance gut health. By doing so the aim was to develop tailor-made nutritional treatments, appropriate for the different management systems. The nutritional treatments were developed in small scale, focused experiments and selected treatments were tested in the large scale facilities of the industrial collaborators, to confirm their applicability on conditions prevailing in the British pig industry.

Scientific objectives, approaches and results

Objective 1. To develop strategies for creep feed provision which promote gut development and set up a gut microflora better able to resist colonisation by pathogenic bacteria during the weaning transition

Objective 1.1. *Investigation of the role of creep feed composition on voluntary intake and the development of the gut microflora*

In discussion with the Project Steering Group it was decided that, i) only pigs weaned at 4 weeks of age should be used, as informed by the sister project AGEWEAN, and ii) the dietary treatments should be expanded to include sodium butyrate which had shown some beneficial effects on gut architecture post-weaning in Objective 1.2. Treatments thus comprised: Control (C), a high digestibility milk-based creep (230 g CP, 18 g fibre, 160 g total lactose/kg); Inulin, as for C with the addition of inulin at 50g/kg (as Raftifeed); Butyrate, as for C with the addition of 3 g/kg esterified butyric acid; Milk, no pelleted creep feed offered but instead liquid milk replacer. Diets were offered ad libitum from 7 days of age until weaning.

- Pre-weaning creep feed manipulation, by inclusion of either sodium butyrate or inulin in the creep, did not deliver any added benefits in post-weaning feed intake, performance or microbial indicators of gut health beyond that provided by a high quality, commercial-specification creep.

Objective 1.2. *To determine whether a fermentable creep diet, or butyrate, accelerate gut development pre-weaning and hence facilitate a smooth transition into the weaned state*

It was agreed by the consortium that the key point of interest in this experiment was to determine whether addition of butyrate to the diet would stimulate growth and development of the proximal digestive tract. The experimental consisted of a 4 x 2 factorial design of sodium butyrate inclusion (0, 1.5, 3 or 6 g /kg) and zinc oxide inclusion (0 vs. 3.1 g/kg). Diets were offered ad libitum from 13 days post-weaning.

- The inclusion of sodium butyrate enhanced gut development and improved feed conversion ratio and may therefore be beneficial in weaner pig diets.
- Zinc oxide supplementation significantly improved all aspects of pig performance and small intestine structure.

Objective 2. To evaluate the consequences of differences in both source and processing conditions of raw materials on in vitro hydration, viscosity and susceptibility to enzyme attack

The influence of processing conditions on the hydration, structural and in vitro digestive characteristics of wheat with different endosperm texture and other cereals including barley, triticale rye, naked oats, whole oats and maize was investigated.

- Soft wheat has different hydration characteristics between batches, underlining the importance of fully characterising the hydration and physicochemical properties of cereals before using them in trials. As starch needs to hydrate to allow effective enzyme hydrolysis, a difference in hydration patterns can be an important variable in digestibility.
- Endogenous alpha amylase activity may be a significant variable influencing both in vitro rheological and in vivo digestibility data.

- Principal component analysis has revealed that it is possible to predict in vivo small intestinal starch digestibility in post-weaned piglets with in vitro data.

Objective 3. To quantify the consequences of differences in both source and processing conditions on nutritional value of starches, protein and NSPs contained within raw materials commonly used in weaned pig diets; to assess environmental impact through estimations of faecal/urinary output

The objective was changed, with the full knowledge and approval of the committee including all sponsors, to concentrate on cereals. Trial 3.1. compared two diets differing only in wheat of different endosperm texture (1 hard, 2 soft). Wheat varieties shared a common genetic background and did not contain the 1B1R characteristic. Trial 3.2 was a 2 x 2 factorial design of wheat endosperm (Hard vs. Soft) and degree of micronising (low vs. high cook). Trial 3.3 consisted of a 2 x 2 factorial design of endosperm texture (Hard vs. Soft) and degree of extrusion (High SME vs. Low SME). Raw soft wheat was used as a control. Trial 3.4 consisted of 2 trials each feeding one of four diets differing only in raw cereal type (trial 3.4a; wheat, barley, rye and triticale) and (trial 3.4b; wheat, naked oats, whole oats and maize).

- The use of processed wheat (by micronisation or extrusion) in the diet of weaned pigs is associated with enhanced nutritional value in terms of starch digestibility (cooking lessened the reduction in small intestinal starch digestibility usually seen around day 4 post-weaning).
- Soft wheat is associated with improved nutritional value in terms of gut environment and N digestibility. It is expected that this will lead to increased confidence in using wheat of particular backgrounds for inclusion into piglet diets.
- Differences exist in the starch digestibility of raw ground cereals within the small intestine of the weaned pig.
- Fermentation in the large intestine of unprocessed cereals may be considerable in the young piglet.
- Of the cereals investigated, maize was the least well-digested over the 14 day post-weaning period.

Objective 4. To quantify the consequences of different sources of 'functional fibre' on the food intake, performance, gut development and health, and nutrient partitioning

Objective 4.1. *The responses to varying levels of 'functional fibre' deriving from plant sources in terms of food intake, performance and gut health will be quantified from weaning to 14 days post-weaning.*

It was agreed by the project steering committee that pure NSP sources should be used rather than more typical dietary fibre sources in order to better understand the effects of NSP solubility. The trial consisted of a 3 x 2 factorial design of NSP type (soluble (sNSP); inulin vs. insoluble NSP (iNSP); methyl cellulose) versus inclusion level (L; 50 vs. M; 100 vs. H; 150 g NSP/kg) with the addition of a negative (C) and positive control (C+). The C diet contained an amount of NSP corresponding to the M diets and was approximately 50:50 sNSP:iNSP. The C+ diet was identical to the C diet with the addition of AGP.

- To minimise the risk of post-weaning diarrhoea whilst maximising performance, diets containing sources of predominantly soluble NSP, which do not lead to increased digesta viscosity, such as inulin, should be recommended.

Objective 4.2. *The interactions between level or source of 'functional fibre' in the weaner diet and weaning age on food intake and behaviour, performance and gut health will be quantified from weaning to 14 days post-weaning.*

It was agreed by the project steering committee that the objective be slightly amended to test the effect of non-starch polysaccharides that do not affect digesta viscosity on the consequences of sub-clinical post-weaning in newly weaned pigs challenged with enterotoxigenic Escherichia coli (ETEC). The trial consisted of a 2 x 2 x 2 factorial combination of NSP solubility (iNSP vs. sNSP), inclusion level (L vs. H) and ETEC challenge (infected vs sham). Pigs in the infected group were challenged *per os* with 109 ETEC (E. coli O149) on day 4 post-weaning.

- sNSP per se are not detrimental to pig health
- Increasing the concentration of NSP in weaner diets that do not increase digesta viscosity may have a beneficial effect on gut health and help protect against post-weaning diarrhoea.

Objective 4.3. *The interactions between level or source of 'functional fibre' and crude protein content in the weaner diet on food intake, performance, nitrogen partitioning and gut health will be quantified from weaning to 14 days post-weaning*

The trial consisted of a 3 x 2 factorial design experiment compared dietary crude protein content (L; 150 vs. M; 190 vs. H; 230g CP/kg) and inulin inclusion (-, 0 vs. +, 50 g/kg). Pigs were challenged *per os* with enterotoxigenic *Escherichia coli* (ETEC) post-weaning.

- Inulin inclusion may help to protect against PWC, particularly in pigs fed diets containing high levels of crude protein.

Objective 5. To quantify the consequences of protein nutrition post-weaning on the food intake, performance, gut developments and health, and nutrient partitioning

Objective 5.1. *The response to varying levels of crude protein content in the weaner diet in terms of feed intake, performance and gut health will be quantified from weaning to 14 days post-weaning.*

The experiment consisted of a 3 x 2 factorial combination of dietary protein content (L; 130 vs. M; 180 vs. H; 230 g CP/kg) and main protein source (dried skimmed milk powder (DSMP) vs. soya (SOYA)) plus a control containing 230 g CP/kg, DSMP and in-feed AGP. Diets were fed to 4 week weaned pigs for 2 weeks post-weaning.

- Diets low in crude protein content and those containing DSMP may be fed to newly weaned pigs in order to improve gut health and decrease the risk of post-weaning diarrhoea.

Objective 5.2. *The interactions between crude protein level in the weaner diet and weaning age on food intake, performance and gut health will be quantified from weaning to 3 weeks post-weaning*

The experiment consisted of a 2 x 2 x 2 factorial combination of weaning age (4 vs. 6 weeks), dietary protein content (H vs. L) and experimental ETEC challenge (+ vs. -). An additional 4 treatments were added to allow the effect of protein source (DSMP vs. SOYA) and AGP inclusion (yes vs. no) to be investigated in challenged pigs of both weaning ages. Pigs were challenged *per os* with ETEC on day 3 post-weaning. Pigs were fed until 10 weeks of age.

- Diets low in crude protein content may be fed to newly weaned pigs in order to improve gut health and decrease the risk of post-weaning diarrhoea. This may be particularly beneficial in younger pigs and under less favourable conditions with increased disease challenge.
- The small penalty on performance observed in pigs fed low protein diets compared to those fed high protein diets for 2 weeks post-weaning was no longer present at 10 weeks of age.

Objective 6. To investigate the consequences of the acid buffering characteristics of the post-weaning diet on food intake, performance, gut health and nutrient balance

The experiment consisted of a 2 x 2 factorial design of organic acid inclusion (0 vs. 12 g formic/propionic acid blend/kg) and phytase inclusion (0 vs. 500 FTU phytase/kg diet). Diets were therefore control, control plus acid, control plus phytase and control plus both acid and phytase. Acid binding capacities of these diets were calculated to be 690, 644, 652 and 607 respectively.

- There was no effect of formic acid or phytase on pig gut health or performance.
- The inclusion of phytase may be a viable alternative to the addition of inorganic phosphorus to weaner pig diets.

Objective 7. To investigate the utilisation of rapeseed meal as a home grown protein source for weaned pigs

A split litter design was used to investigate the response to 4 levels of inclusion of micronised whole rapeseed in the diet (0, 5, 10 or 20 %) during the first 4 weeks after weaning when piglets were weaned at either 4 or 6 weeks of age. Rapeseed substituted for soya in diets formulated commercially to provide the same levels of net energy and ileal digestible ideal protein.

- Micronised whole rapeseed has the potential to be a cost effective home-grown protein source in diets for weaned piglets in scaled up production, since inclusion levels greater than previously accepted can be used without adversely affecting health, feed conversion efficiency or feed cost per kg gain. However, strategies to overcome the detrimental effect on intake at inclusion levels above 5 % need to be further developed.

Objective 8. To investigate the consequences of nutritional treatments post-weaning on the occurrence and pathogenesis of post-weaning colibacillosis

The consortium decided that the two experiments originally planned should be combined into a single 2 x 2 factorial study of lactation environment (Indoor

vs. Outdoor) and ZnO inclusion (0 vs. 3.1 g/kg). Group-housed four week weaned pigs were challenged per os with ETEC on day 4 post-weaning.

- Outdoor rearing of pigs significantly reduced faecal ETEC counts and increased intestinal mass. However, rearing environment had no effect on pig health or performance in the presence of an ETEC challenge and did not affect small intestine morphology.
- The addition of 3100ppm ZnO to the diet significantly reduced faecal ETEC counts, improved the morphology of the upper small intestine and had beneficial effects on small and large intestine lactobacilli to coliform ratios. These responses were associated with marked improvements in feed intake, growth rate and feed efficiency and were paralleled by superior pig health and cleanliness.

Objective 9. To investigate the association between lactation environment, weaning age and post-weaning diet on the performance and gut health of pigs until 8 weeks of age

Trial 9.1. consisted of a 2 x 2 x 2 factorial arrangement of lactation environment (indoor vs. outdoor), weaning age (4 vs. 6 weeks of age) and AGP inclusion (0 vs. 3.1g ZnO/kg and 40mg Avilamycin/kg). Trial 9.2. consisted of a 2 x 2 factorial arrangement of ZnO inclusion (0 vs. 3.1 g/kg) and esterified butyrate inclusion (0 vs. 1.5 g/kg) using 4 week weaned pigs. Esterified butyrate was used instead of sodium butyrate to try to move the site of dissociation and hence butyrate action further down the small intestine.

- Outdoor reared piglets performed better pre and post-weaning than those reared indoors, although pre-weaning mortality rate was higher in outdoor rearing.
- Regardless of rearing environment all pigs responded positively to both zinc oxide and antimicrobial growth promoters.
- Delaying weaning until 6 weeks of age disadvantaged indoor reared piglets, but may not be disadvantageous to outdoor reared piglets, depending upon the subsequent feeding regime.
- Outdoor reared pigs showed an improved gut development post-weaning compared to the indoor reared pigs, possibly due to the opportunities to forage and consume substrates prior to weaning.
- Esterified butyrate did not affect post-weaning pig performance regardless of rearing environment.

Objective 10. To translate experimental findings to feeding management treatments applicable in the British Pig Industry

Objective 10.1: MLC Stotfold Large Scale trial 1: *The effect of protein level and diet quality on the performance of newly weaned pigs on a large scale facility from weaning until slaughter*

A 2 x 2 factorial design experiment compared dietary crude protein level (H; 230 vs. L; 170 g CP/kg) and diet quality (h vs. l). 400 four weeks weaned pigs were offered *ad libitum* access to one of the four dietary treatments for 14 days post-weaning. The high (h) quality diets contained cooked cereals (wheat, dehulled oats and maize) and animal protein (fish meal and dried skimmed milk powder), whereas the low (l) quality diets contained raw cereals (wheat, dehulled oats and maize) and plant protein (soya bean meal and full fat soya). From day 14 until the end of the weaner phase (approx. 30 kg) pigs were fed standard

commercial diets. From then until slaughter (approx. 100 kg) pigs had *ad libitum* access to the same liquid feed diet.

- Under commercial conditions, pigs offered high quality (cooked cereals and animal protein sources) had improved health and performance over the 14 day post-weaning period compared to those fed low quality diets (raw cereals and plant protein sources). There was however no long term effect of post-weaning diet on the health and performance.

Objective 10.2: MLC Stotfold Large Scale trial 2: *The effect of lactose level and inulin inclusion on the performance of newly weaned pigs on a large scale facility*

A 2 x 2 factorial design experiment compared dietary lactose level (L; 100 vs. H; 200 g /kg) and inulin inclusion (0 vs. 20 g/kg). 340 four-week weaned pigs were offered *ad libitum* access to one of the four dietary treatments for 14 days post-weaning. From day 14 pigs were fed standard commercial diets until the end of the weaner phase at approximately 30 kg body weight (days 14+). Pigs were housed in groups of 6 to 8 whilst on trial.

- Increasing lactose content and the inclusion of inulin in the post-weaning diet had no clear effect on the health and performance of pigs raised under commercial conditions; both were maintained high throughout the trial.

Objective 10.3: Provimi, Sancho Royo Large scale trial 1: *The effects of different production parameters in the hydrothermal treatment of wheat on the performance of newly weaned pigs on a large scale facility.*

As Objectives 2 and 3 showed that wheat endogenous α - amylase activity influences its nutritional value, a wheat with low α - amylase activity used. This was expected to present pigs with the greatest challenge post-weaning. A diet containing 50% of the wheat was subjected to different degrees of extrusion (SME): no extrusion (control), low (L), medium (M) and high (H). The CP of all resulting diets was 225g/kg. The resulting diets were each fed to 220 pigs weaned at 25 days of age for a period of 11 days (day 1-11) in a pre-starter diet, and then another 15 days (day 11-26) in a starter diet (880 pigs in total).

- Under commercial conditions, degree of extrusion had a significant effect on health and performance of pigs over the immediate post-weaning period. The non-extrusion diet led to the poorest performance.
- Extrusion improved weight gain, with no differences between the level of extrusion over day 1-11 post-weaning, whilst intake increased with increasing level of extrusion. However, extrusion did not improve weight gain or intake between day 11-26 post-weaning.
- Differences in pig live weight between the non-extrusion diet and the other three diets were no more evident by the end of the experiment, i.e. 26 days post-weaning.

Objective 10.4: Provimi, Sancho Royo Large Scale Trial 2: *The effects of wheat amylase activity and hydrothermal treatment of wheat on the performance of newly weaned pigs on a large scale facility.*

A 2x2 factorial design experiment compared two wheats of different levels of α - amylase activity (high and low) and degrees of extrusion (low (L) and high (H)). The levels of extrusion were similar to the L and H used in the above trial. The two wheats derived from different varieties, previously used in Objectives 2 and 3. The experimental protocol essentially followed the details of the previous

trial with 880 pigs weaned at 25 days of age being allocated to the four resultant treatments for 26 days.

- There was an interaction between amylase content and degree of extrusion between day 1-11 post-weaning. At low levels of amylase, extrusion level did not affect pig performance. However, at high levels of amylase, increased level of extrusion resulted in higher intake and weight gain.
- A different interaction between amylase content and degree of extrusion was apparent between day 11-26 post-weaning. At low levels of amylase, extrusion level again did not affect pig performance, but at high level of amylase highest growth was observed at low level of extrusion. However, extrusion increased intake at both levels of amylase.
- In contrast to the experiment under Objective 10.3, differences in pig live weight were observed by the end of the 26-day period, with the highest body weight achieved on high amylase diets that are processed at high levels of extrusion.

It is appreciated that as the two wheats used were from different varieties, differences in other characteristics than α - amylase activity may have contributed to differences in performance.

Implications

Among the expected benefits from outcomes of the project are:

- Decreased occurrence of post-weaning diarrhoea leading to improved pig health and welfare
- Increased profits as a result of improved post-weaning performance
- Improved feed efficiency resulting in a decrease in nitrogen output and reduced environmental impact
- Potential increase in market for UK cereals and oilseeds and decrease in protein imports
- Reduced environmental burden of minerals and chemical residues
- Reduced dependency on antimicrobial agents

Present and projected level of knowledge transfer

Project results have been communicated to the pig feed industry, animal scientists, pig veterinarians, pig farmers, and government departments by various means. Currently these include ~20 refereed and review papers, 25 conference papers, BPEX/MLC industry meetings, an exhibit at the 2006 Pig and Poultry Fair and articles in technical magazines, including HGCA topic sheets and BPEX Tech Talk.

During the project there was close collaboration with the industrial partners which has enabled them to make use of the scientific findings in the formulation of weaner diets and within their own R&D programmes. Listed below are some examples of the current and projected levels of knowledge transfer.

- ABN are in the process of initiating research into the area of EAA:lysine, EAA:NEAA relationships and lysine to crude protein ratios, following on from the clear message that lower protein diets reduced diarrhoea, but also performance. They also have a pilot project underway to assess whether genomics can aid their follow up R&D where some aspects of the project are being repeated.

- As a direct outcome of the project, Frank Wright Ltd implemented into their protocols the inclusion of both formic acid and phytase in piglet diets. With potential future legislation regarding the use of therapeutic levels of zinc oxide in piglet diets, the benefits of organic acids and phytase in the initial post-weaning period will be further explored in their R&D programme in relation to performance and health.
- The results of the work looking at cereal processing techniques and protein sources/dietary levels is particularly relevant when looking at raw material selection for piglet rations, something which is becoming ever more important as raw material prices escalate, especially for certain milk and marine protein sources.
- The project has succeeded in demonstrating the positive nutritional and health benefits which the inclusion of cereals and oilseeds in weaner diets can have. This information will enable the arable and pig sectors to work together to ensure arable farmers supply wheat of optimum quality for inclusion in pig feeds.
- The project has shown that inclusion of oilseed rape as a home-grown protein source at greater levels than previously accepted can be used without detriment to pig health or nutrition.
- HGCA has worked with the consortium to publicise the findings of the project and will continue to utilise a range of knowledge transfer activities to ensure maximum benefit from the research.
- The programme has substantiated much of Provimi's previous research and development work carried out at their laboratories and trial farms around the world. In particular the effects of nutrition on gut health and gut integrity have complemented their own programmes of work and also the work on starch degradation and starch kinetics has contributed to knowledge and data in this important area. Provimi's future programmes will develop some of these themes and there is a significant commercial interest in these two areas of work. The large scale work on starch kinetics and cereal types will form an important part of Provimi's knowledge base in this area.
- BPEX will continue to promote the outputs from the Nutwean project through its KT mechanisms such as Action for Productivity, Target Farm Action, website, seminars, pig discussion groups and conferences. Considerable KT output has already been delivered during the project's lifecycle. BPEX and BSAS are planning a joint occasional meeting for July 2008 targeting industry attendance. Outputs from the Nutwean project will form a key part of this meeting.

Future R&D

The wide ranging scope of this project has pointed to several potential further research areas. The over-riding area is the need for a much greater understanding of effects of factors affecting the balance and composition of the gut microflora and the impact this may have on health and performance. This project studied effects of increased gut acidity potential by reducing buffering capacity of feeds and adding acids. The results suggested that, in some circumstances, acid may produce similar performance to zinc oxide. Zinc oxide is extremely effective at reducing post-weaning diarrhoea and if this material was removed from the industry effects would be very damaging unless alternatives could be found. This work has indicated that acidification may be a way forward and warrants further investigation.

Current raw material prices of feedstuffs used in starter feeds is forcing looking at alternative sources. Thus, impact of utilising materials of lower digestibility on the level and balance of gut microflora is of fundamental importance. This work has demonstrated that materials of lower digestibility, or offering a different type or level of fermentable substrate, have an impact on the balance of microflora but effects on disease per se is not fully understood. Similarly the role of processing cereals on gut microflora is worthy of further investigation together with further evaluation of the food industry techniques of measuring the processing effects.

ABN/Primary Diets are in the process of initiating research into the area of EAA:lysine, EAA:NEAA relationships and lysine to Crude Protein ratios, following on from the clear message that lower protein diets reduced diarrhoea, but also performance. They also have a pilot project underway to assess whether genomics can aid their follow up R&D. They are repeating some aspects of the project with a genomic element in order to assess its potential contribution.

The focus of the project was on consequences of nutritional manipulation of weaner diets on performance of weaned pigs during the critical post-weaning period. The nutritional manipulations imposed showed effects on health and performance of weaners in the short-term. The question that arises is whether these effects have any long-term consequences on pig performance to slaughter, which is inevitably linked with compensatory or catch up growth. This project only performed one trial where the performance of pigs was followed to slaughter. There was a significant difference in the body weight of pigs two weeks post-weaning, with pigs fed low protein diets being lighter than their counterparts on high protein diets and having increased average daily gains. However, whilst this difference in body weight was no longer present at approx. 7 weeks of age suggesting there may have been some compensatory growth by pigs in the low protein group, there was no significant effect of protein level on average daily gain in this period suggesting a lack of compensation.

One trial within the overall research programme addressed the issue of strategies of creep feed provision on the food intake and performance of pigs post-weaning. This trial and the outcomes of the AGEWEAN research project suggest that there is substantial variability in post-weaning food intake both within and between litters. An investigation into the causes of this variation may be warranted.

Future research opportunities which will reduce losses to the environment (e.g. zinc and nitrogen), limit antibiotic use and deliver high levels of animal performance will focus on further development of dietary strategies involving the design of diets with the nutraceutical qualities to address specific needs of weaner pigs facing specific genetic, environmental and management challenges. These include selected use of specific feeds or laboratory characterized feed ingredients, and diet-formulations minimizing the risk of digestive disorders while optimizing health and productivity.

BPEX future R&D planning will review outputs from Nutwean and the wider weaner pig research programme, working in partnership with Defra to deliver industry and policy needs underpinning sustainable development.

APPENDIX: List of full technical reports and reviews

Below a list of the Objectives as addressed in NUTWEAN, with mentioned underneath details on the associated technical report available as appendices. Several types of technical reports are included:

Reports:	reports written for use by parnters and dissemination through means available with consortium partners but not written as a scientific paper
Draft paper:	report in the form of a draft paper but not (yet) submitted to a (identified) peer refereed journal
Submitted paper:	report in the form of a draft paper and submitted to a peer refereed journal and under consideration of publication
Paper:	report in the form of a paper published or in press in a peer refereed journal

In addition, reviews have been produced across Objectives. These are listed separately.

List of reports

Objective 1.1. Investigation of the role of creep feed composition on voluntary intake and the development of the gut microflora.
Report: Investigation of the role of creep feed composition on voluntary intake and development of the gut microflora. (being prepared as paper: Guy, J.H., Brett, M.R., Edge, H.L., Miller, H.M. and Edwards, S.A. Effect of creep feed composition on feed intake, growth rate and gut microflora of piglets before and after weaning).

Objective 1.2. To determine whether a fermentable creep diet, or butyrate, accelerate gut development pre-weaning and hence facilitate a smooth transition into the weaned state.
Draft paper: Carroll, S.M., S. Jagger, P. Toplis and H.M. Miller. The effect of the inclusion of sodium butyrate and zinc oxide in weaner pig diets upon feed intake, piglet performance and gut structure.

Objective 2. To evaluate the consequences of differences in both source and processing conditions of raw materials on in vitro hydration, viscosity and susceptibility to enzyme attack.
Paper: White, G.A., Doucet, F.J., Hill, S.E. and Wiseman, J. (2008). Physicochemical properties and nutritional quality of raw cereals, and near-isogenic hard and soft endosperm wheat cultivars for newly-weaned piglets. *Animal* (in press).
Paper: White, G.A., Doucet, F.J., Hill, S.E. and Wiseman, J. (2008). Physicochemical changes to starch granules during micronisation and extrusion processing of wheat, and their implications for starch digestibility in the newly-weaned piglet. *Animal* (in press).
Draft paper: Doucet, F.J., Hill, S.E., White, G. and J. Wiseman. Assessment of the milling behaviour and intrinsic hydration properties of hard and soft endosperm wheat cultivars.

Draft paper: Doucet, F.J., Hill, S.E., White, G. and J. Wiseman. Effects of micronisation of wheat on starch structure, hydration properties and susceptibility to in vitro amylolytic digestion, and the importance of endosperm texture.

Objective 3. To quantify the consequences of differences in both source and processing conditions on nutritional value of starches, protein and NSPs contained within raw materials commonly used in weaned pig diets; to assess environmental impact through estimations of faecal/urinary output.
Draft paper: Doucet, F.J., White, G, Wulfert, F., Hill, S.E. and J. Wiseman. Predicting in vivo starch digestibility coefficients in newly-weaned piglets from the rapid in vitro assessment of diets. F.J. Doucet, G.A. White, F. Wulfert, S.E. Hill, and J. Wiseman. 2007. British Journal of Nutrition (in preparation).

Objective 4.1. The responses to varying levels of 'functional fibre' deriving from plant sources in terms of food intake, performance and gut health will be quantified from weaning to 14 days post-weaning.
Paper: Wellock, I.J., Houdijk, J.G.M. and Kyriazakis. I. (2007). Effect of dietary non-starch polysaccharide solubility and inclusion level on gut health and the risk of post weaning enteric disorders in newly weaned piglets. *Livestock Science* **108**: 186-189.

Objective 4.2. The interactions between level or source of 'functional fibre' in the weaner diet and weaning age on food intake and behaviour, performance and gut health will be quantified from weaning to 14 days post-weaning.
Paper: Wellock, I.J., Fortomaris, P.D., Houdijk, J.G.M., Wiseman, J. and I. Kyriazakis. (2007). The consequences of non-starch polysaccharide solubility and inclusion level on the health and performance of weaned pigs challenged with enterotoxigenic *Escherichia coli. British Journal of Nutrition* **99**: 520-530.

Objective 4.3. The interactions between level or source of 'functional fibre' and crude protein content in the weaner diet on food intake, performance, nitrogen partitioning and gut health will be quantified from weaning to 14 days post-weaning.
Submitted paper: Wellock, I.J., Houdijk, J.G.M. and I. Kyriazakis. Consequences of dietary protein content and inulin inclusion on health and performance of newly weaned pigs exposed to an enterotoxigenic *Escherichia coli* challenge. *Journal of Animal Science* (submitted).

Objective 5.1. The response to varying levels of crude protein content in the weaner diet in terms of feed intake, performance and gut health will be quantified from weaning to 14 days post-weaning.
Paper: Wellock, I.J., Fortomaris, P.D., Houdijk, J.G.M. and I. Kyriazakis. (2007). The effect of dietary protein supply on the performance and risk of post-weaning enteric disorders in newly weaned pigs. *Animal Science* **82**:327-325.

Objective 5.2. The interactions between crude protein level in the weaner diet and weaning age on food intake, performance and gut health will be quantified from weaning to 3 weeks post-weaning.
Paper: Wellock, I.J., Fortomaris, P.D., Houdijk, J.G.M. and I. Kyriazakis. (2007). Effect of weaning age, protein nutrition and enterotoxigenic *Escherichia coli* challenge on the health of newly weaned piglets. *Livestock Science* **108**:102-105.

Paper: Wellock, I.J., Fortomaris, P.D., Houdijk, J.G.M. and I. Kyriazakis. (2008). The consequences of dietary protein supply, weaning age and experimental enterotoxigenic *Escherichia coli* infection in newly weaned pigs: 1) performance. *Animal* (in press)
Paper: Wellock, I.J., Fortomaris, P.D., Houdijk, J.G.M. and I. Kyriazakis. (2008). The consequences of dietary protein supply, weaning age and experimental enterotoxigenic *Escherichia coli* infection in newly weaned pigs: 2) health. *Animal* (in press).

Objective 6. To investigate the consequences of the acid buffering characteristics of the post-weaning diet on food intake, performance, gut health and nutrient balance.
Submitted paper: Carroll, S.M., Ilsley, S.E., Toplis, P., Blanchard P. and Miller, H.M. The effect of the inclusion of formic acid and phytase in weaner pig diets upon feed intake, piglet performance and gut structure. *Animal* (submitted).

Objective 7. To investigate the utilisation of rapeseed meal as a home grown protein source for weaned pigs.
Report: The utilisation of oilseed rape as a home grown protein source for piglets weaned at different ages (prepared as paper: Wattanakul W, Hillman K, Guy JH, Toplis P and Edwards SA. Micronised whole rapeseed as a home-grown protein source for pigs weaned at different ages).

Objective 8. To investigate the consequences of nutritional treatments post-weaning on the occurrence and pathogenesis of post-weaning colibacillosis.
Submitted paper: Slade, R.D., Carroll, S.M., Reynolds, F.H., White, K.S., Wellock, I.J., Kyriazakis, I. and Miller, H.M. Effect of rearing environment and dietary zinc oxide level on the response of group housed weaned pigs to enterotoxigenic *Escherichia coli* O149 challenge. *Journal of Animal Science* (submitted)

Objective 9. To investigate the association between lactation environment, weaning age and post-weaning diet on the performance and gut health of pigs until 8 weeks of age.
Paper: Miller, H.M., Carroll, S.M., Reynolds, F.H. and Slade, R.D. (2007). Effect of rearing environment and age on gut development of piglets at weaning. Livestock Science 108: 124-127.
Draft paper: Miller, H.M., Toplis, P. and Slade, R.D. Can outdoor rearing and increased weaning age compensate for the removal of in-feed antibiotic growth promoters and zinc oxide? *Livestock Science* (in preparation)
Draft paper: Carroll, S.M. and Miller, H.M. The effect of rearing environment, zinc oxide and butyrate upon feed intake, performance and gut structure in the newly weaned pig.

Objective 10. To translate experimental findings to feeding management treatments applicable in the British Pig Industry.
Submitted paper: Wellock, I.J., Houdijk, J.G.M., Miller, A.C., Gill, B.P. and Kyriazakis, I. The effect of weaner diet protein level and diet quality on the long-term performance of pigs to slaughter. *Journal of Animal Science* (submitted)
Report: The effects of lactose inclusion level and inulin inclusion in diets fed for the first 14 days post-weaning on the health and performance of pigs from weaning to the end of the weaner stage.

Report: The effects of different production parameters in the hydrothermal treatment of wheat on the performance of newly weaned pigs on a large scale facility.
Report: The effects of wheat amylase activity and hydrothermal treatment of wheat on the performance of newly weaned pigs on a large scale facility.

List of reviews

Objective 1.2: Miller, H.M. and Slade, R.D. 2006. Organic acids, pig health and performance. *The Pig Journal* **57**: 140-149.

Objectives 2 and 3: Doucet, F.J., White, G., Wiseman, J., and Hill, S.E. (2006). Physicochemical changes to starch structure during processing of raw materials and their implications for starch digestibility in newly-weaned piglets. In: *Recent Advances in Animal Nutrition*. (Eds P.C. Garnsworthy and J. Wiseman) Nottingham University Press, Nottingham, UK. pp. 313-330.

Objectives 4.1, 4.2 and 4.3: Wellock, I.J., Houdijk, J.G.M., Skoufos, I., Fortomaris, P.D. and I. Kyriazakis. (2007). Is there a role for dietary fibre in the control of post-weaning colibacillosis in the newly weaned pig? *The Pig Journal* **59**: 131-143.

Objectives 5.1, 5.2 and 7: Wellock, I.J., Houdijk, J.G.M., Fortomaris, P.D., Edwards, S.A. and I. Kyriazakis. (2006). Too much of a good thing – protein, gut health and performance. *The Pig Journal* **57**:158-172.